

CLAIMS

What is claimed is:

- 1 1. A multi-layer vertical comb-drive actuator comprising:
 - 2 a) a first comb structure having a plurality of first
3 comb fingers; and
 - 4 b) a second comb structure having a plurality of second
5 comb fingers, wherein the second comb structure is
6 positioned such that the second comb fingers are
7 interdigitated and self aligned with the first comb
8 fingers;
9 wherein one or more of the first and second comb fingers
10 includes at least one first conductive layer and at least
11 one second conductive layer, wherein the first and second
12 conductive layers are electrically isolated from each
13 other.
- 1 2. The multi-layer vertical comb-drive actuator of claim 1
2 wherein the first and second conductive layers are
3 electrically isolated by an insulating layer.
- 1 3. The multi-layer vertical comb-drive actuator of claim 1
2 wherein the first and second conductive layers are
3 isolated by an air gap.
- 1 4. The multi-layer vertical comb-drive actuator of claim 1,
2 wherein one or more of the first comb fingers include
3 first and second conductive layers.
- 1 5. The multi-layer vertical comb-drive actuator of claim 4,
2 wherein one or more of the second comb fingers of the
3 second comb structure has at least one first conductive
4 layer that is substantially aligned with the first

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5 conductive layer of the first comb fingers of the first
6 comb structure.

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1 6. The multi-layer vertical comb-drive actuator of claim 5,
2 wherein an application of a voltage between the second
3 conductive layers of the first comb fingers and the first
4 conductive layers of second comb fingers causes relative
5 movement between the first and second comb structures.

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5 7. The multi-layer vertical comb-drive actuator of claim 5,
6 wherein the second comb fingers further comprise a
7 second conductive layer, wherein the first and second
8 conductive layer of the second comb fingers are
9 electrically isolated from each other.

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4 8. The multi-layer vertical comb-drive actuator of claim 7,
5 wherein the first and second conductive layers of the
6 second comb fingers are electrically isolated by an
7 insulating layer.

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4 9. The multi-layer vertical comb-drive actuator of claim 7,
5 wherein the first and second conductive layers of the
6 second comb fingers are electrically isolated by an air
7 gap.

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6 10. The multi-layer vertical comb-drive actuator of claim
7 7, wherein an application of a voltage between the first
8 conductive layer of the first comb fingers and the
9 second conductive layer of the second comb fingers
10 causes the second comb structure to move relative to the
11 first comb structure.

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3 11. The multi-layer vertical comb-drive actuator of claim
4 7, wherein an application of a voltage between the
5 second conductive layer of the first comb fingers and

4 the first conductive layer of the second comb fingers
5 causes the second comb structure to move relative to the
6 first comb structure.

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1 12. The multi-layer vertical comb-drive actuator of claim
2 1, wherein the second comb structure has one or more
3 second comb fingers comprising the first and the second
4 conductive layers.

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1 13. The multi-layer vertical comb-drive actuator of claim
2 12, wherein the first comb structure and the second
3 comb structure are fabricated from a common substrate
4 containing the first and second conducting layers.

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1 14. The multi-layer vertical comb-drive actuator of claim
2 12, wherein an application of a voltage between the
3 first conductive layers of the first comb fingers and
4 the second conductive layers of the second comb fingers
5 causes the second comb structure to move relative to
6 the first comb structure.

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1 15. The multi-layer vertical comb-drive actuator of claim 1
2 further comprising a means for measuring a capacitance
3 between the first comb fingers and the second comb
4 fingers.

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1 16. The multi-layer vertical comb-drive actuator of claim
2 15 further comprising a feedback mechanism coupled to
3 the capacitance measuring means for controlling a
4 position of the second comb structure.

1 17. The multi-layer vertical comb-drive actuator of claim 1
2 further comprising a rotating element mechanically
3 coupled to the second comb structure.

1 18. The multi-layer vertical comb drive actuator of claim
2 17, wherein the rotatable element is mechanically
3 coupled to a substrate by a flexure.

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1 19. The multi-layer vertical comb-drive actuator of claim
2 17 further comprising:

- 3 a) a frame mechanically coupled to the rotatable
4 flexure and hence the rotating element;
5 b) a second rotatable flexure disposed along a second
6 axis and mechanically engaged with the frame;
7 c) a third comb structure having a one or more third
8 comb fingers; and
9 d) a fourth comb structure having one or more fourth
10 comb fingers, wherein the fourth comb structure is
11 positioned such that the fourth comb fingers of
12 the fourth comb structure are interdigitated with
13 the third fingers of the third comb structure;

14 wherein one or more of the third and fourth comb
15 structures have one or more comb fingers including at
16 least one first and at least one second conductive
17 layers, wherein the first and second conductive layers
18 are electrically isolated from each other.

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1 20. The multi-layer vertical comb-drive actuator of
2 claim 19, wherein the first and second conductive
3 layers are electrically isolated by an insulating
4 layer.

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2 21. The multi-layer vertical comb-drive actuator of
3 claim 19, wherein the first and second conductive
4 layers are electrically isolated by an air gap.

- 1 22. The multi-layer vertical comb drive actuator of
2 claim 19, wherein the first, second, third and
3 fourth comb structures are substantially co-planar.
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- 1 23. The multi-layer vertical comb-drive actuator of claim
2 19, wherein the axis and the second axis are
3 substantially orthogonal.
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- 1 24. The multi-layer vertical comb-drive actuator of claim
2 19, wherein the second rotatable flexure is attached to
3 a substrate.
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- 1 25. The actuator of claim 19 wherein the first comb
2 structure is mechanically coupled to the frame and
3 wherein the fourth comb structure is mechanically
4 coupled to the frame.
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- 1 26. The multi-layer vertical comb-drive actuator of
2 claim 19, wherein one or more of the third comb fingers
3 include the first and second conductive layers.
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- 1 27. The multi-layer vertical comb-drive actuator of
2 claim 26, wherein one or more of the fourth comb
3 fingers has at least one first conductive layer aligned
4 with the first conductive layer one or more of the
5 third comb fingers.
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- 1 28. The multi-layer vertical comb-drive actuator of
2 claim 27, wherein an application of a voltage between
3 the second conductive layer of the third comb fingers of
4 and the first conductive layer of fourth comb fingers
5 causes the fourth comb structure to move relative to the
6 third comb structure, thereby causing the rotating
7 element to rotate about the second axis.

- 1 29. The multi-layer vertical comb-drive actuator of
2 claim 28, wherein one or more of the fourth comb
3 fingers includes a second conductive layer aligned with
4 the second conductive layer of the third comb
5 structure, wherein the first and second conductive
6 layers of the fourth comb fingers are electrically
7 isolated from each other.
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- 1 30. The multi-layer vertical comb-drive actuator of
2 claim 29, wherein the first and second conductive
3 layers of the fourth comb fingers are electrically
4 isolated by an insulating layer.
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- 1 31. The multi-layer vertical comb-drive actuator of
2 claim 29, wherein the first and second conductive
3 layers of the fourth comb fingers are electrically
4 isolated by an air gap.
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- 1 32. The multi-layer vertical comb-drive actuator of
2 claim 29, wherein an application of a voltage between
3 the first conductive layers of the third comb fingers
4 and the second conductive layer of the fourth comb
5 fingers causes the fourth comb structure to move
6 relative to the third comb structure, thereby causing
7 the rotating element to rotate about the second axis.
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- 1 33. The multi-layer vertical comb-drive actuator of
2 claim 19, wherein the fourth comb structure has one or
3 more fourth comb fingers comprising the first and the
4 second conductive layers.
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- 1 34. The multi-layer vertical comb-drive actuator of
2 claim 33, wherein the third comb structure has one or
3 more first comb fingers comprising at least one first

4 conductive layer in aligned with the first conductive
5 layers of the fourth comb fingers.
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1 35. The multi-layer vertical comb-drive actuator of
2 claim 34, wherein an application of a voltage between
3 the first conductive layers of the third comb fingers
4 and the second conductive layers of the fourth comb
5 fingers causes the fourth comb structure to move
6 relative to the third comb structure, thereby causing
7 the rotating element to rotate about the second axis.

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1 36. The multi-layer vertical comb-drive actuator of
2 claim 19 further comprising a means for measuring a
3 capacitance between the third comb fingers of the and
4 the fourth comb fingers.

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1 37. The multi-layer vertical comb-drive actuator of
2 claim 36 further comprising a feedback mechanism
3 coupled to the capacitance measuring means.
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